20-Metres Band Receiver

an unusual double-conversion superhet

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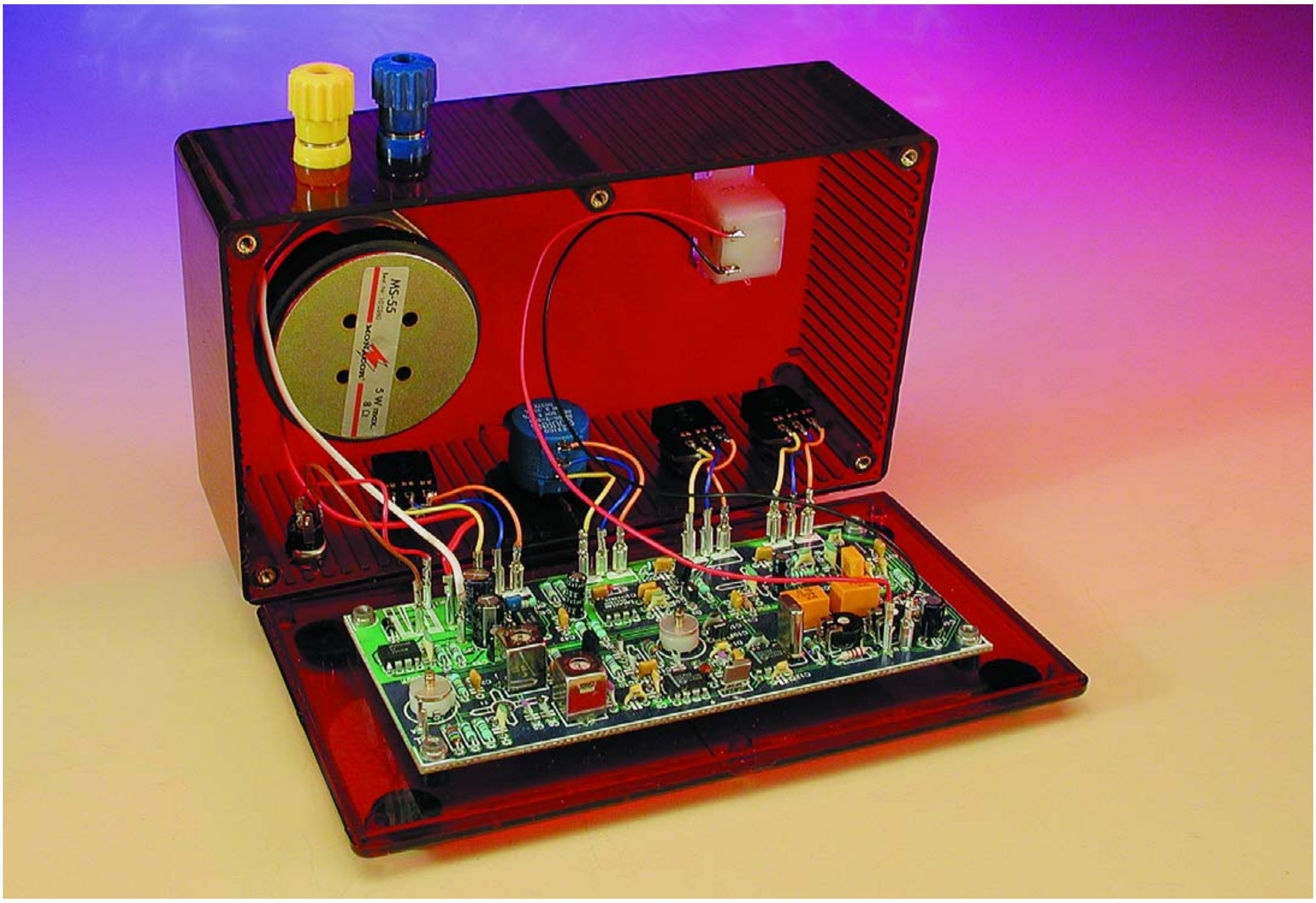
This SSB/CW receiver for the popular 20-m amateur radio band boasts a number of interesting features. Designed as a double-conversion superheterodyne with a direct-conversion demodulator, it offers adjustable IF bandwidth and is remarkably simple to adjust. What's more, the single-board concept makes the receiver easy to build, even by relative newcomers to the radio hobby.



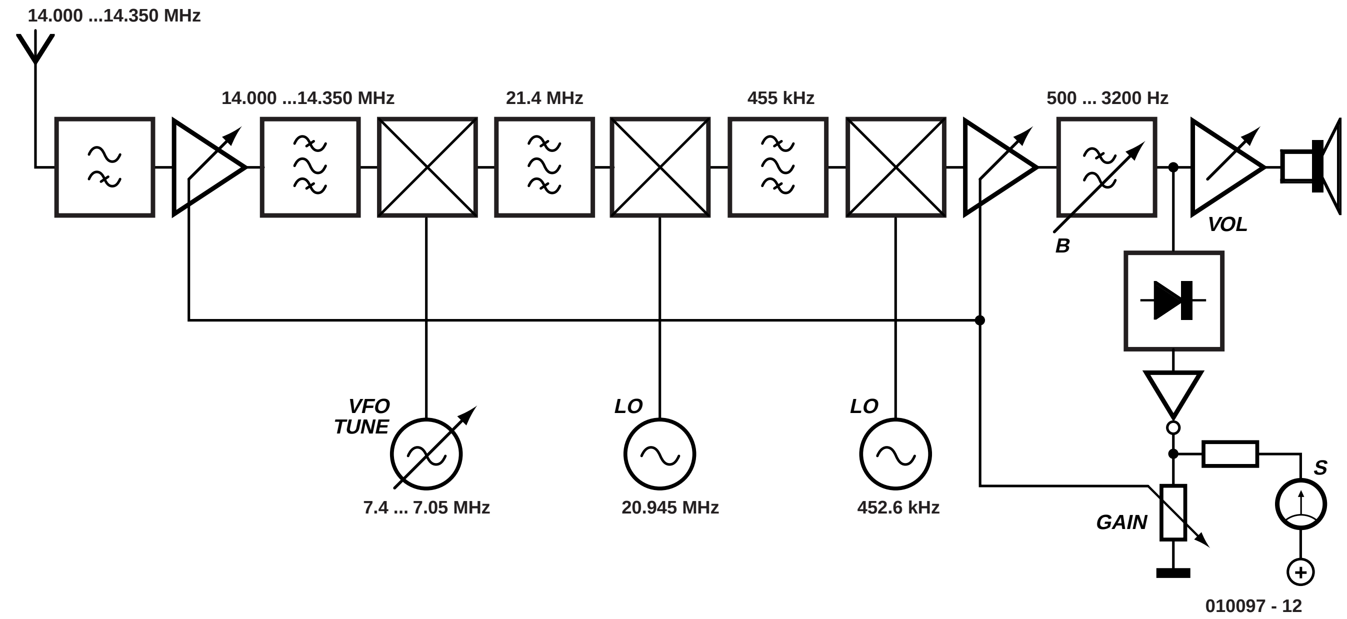


Figure 1. Block diagram of the 20-m band receiver. You are looking at a superheterodyne with three local oscillators.

A number of design aspects should be considered when blueprinting a 20-m band SSB receiver that is going to be reproducible. Besides the obvious aspect "receiver performance" there are other essential considerations like availability and price of the components used. Such considerations immediately rule out the use of, for example, a professional SSB filter which would cost you £30 or more. Furthermore, the concept of the receiver should warrant easy adjustment without special test equipment, allowing those without access to a frequency meter and an oscilloscope to build the project with a fair chance of success.

The receiver described in this article complies with the above design criteria while also offering an excellent price/performance ratio. Let's shortlist some of its features:

- Frequency range 14 – 14.350 MHz (20-m amateur radio band)
- Suitable for SSB, CW, RTTY, fax, SSTV
- Double-conversion superhet with direct-conversion (DC) demodulator
- Sensitivity approx 0.5 µV
- Selectivity adjustable between 0.1 and 2.8 kHz
- Adjustable gain (range 45 dB)
- Image rejection >65 dB
- Audio power up to 0.5 W into 8 Ω
- Max. power consumption 1.5 watts

To this we should add that the receiver is not at all difficult to adjust, and there are no special requirements with regard to the antenna.

Block diagram

The general design of the receiver is best explained with reference to the block diagram in **Figure 1**.

The antenna (RF) signal (14.000 MHz to 14.350 MHz) is taken through a high-pass filter and then amplified. Then follows a filter to suppress image signals, out-of-band and other spurious components. The RF signal is then mixed with the VFO (local oscillator, LO1) which is used to tune the receiver.

With receiver stability in mind, a high VFO frequency is best avoided. That is why a first IF (intermediate frequency) of 21.4 MHz is used in this receiver. This requires a VFO range of 'only' 7.4 to 7.05 MHz. As an additional advantage, image signals then occur at 28.8 to 28.45 MHz, which is sufficiently far from the desired input frequency to allow the use of a relatively simple filter.

The first mixer is followed by a 21.4-MHz bandpass whose main function is to get rid of the unwanted product which is generated in the second mixer when mixing down to 455 kHz with the aid of LO2. This unwanted product occurs at 20.490 MHz (20.945 – 0.455) and is rigorously suppressed by a steep bandpass filter.

Behind the second mixer we have a 455-kHz IF signal available. Normally, this would be amplified and then applied to a product detector. Unfortunately, most (affordable) 455-kHz filters have a bandwidth which is rather too large for our application, even when two such filters are cascaded as in this design. A alternative was found in mixing the 455-kHz IF signal down to AF using a third, frequency-adjustable, oscillator (LO3). This method of mixing the IF signal with a LO3 signal that results in an AF 'beat' signal enables the receiver bandwidth to be effectively determined by the bandwidth of the AF amplifier. Next, an adjustable receiver bandwidth is obtained simply by incorporating a variable filter in the audio section.

The method of using a mixer/LO combination to mix RF down to AF in one go is generally known as 'direct conversion'. In most direct conversion receivers, 'RF' means 'antenna frequency' so the image frequency is inevitably just 3 kHz or so removed from the desired frequency — and this is usually taken for granted. In our design, however, 'RF' means 'second IF' and the 455-kHz filter between the second and third mixer is sufficiently narrow to guarantee adequate suppression of the image signal. In fact, the image rejection may be increased by making the LO3 frequency a bit lower than usual. The underlying principle is as follows:

The –3 dB roll-off points of the 455-kHz filter are at 453 kHz and 456.4 kHz. The LO3 frequency is just below that of the down-converted IF signal, and the image signal is further down, at equal distance. Now, the ingenious bit is to make the lowest frequency of the received signal coincide with the lower limit of the filter. In this way, the distance between the lowest passband frequency and the image frequency is maximized. Consequently, image

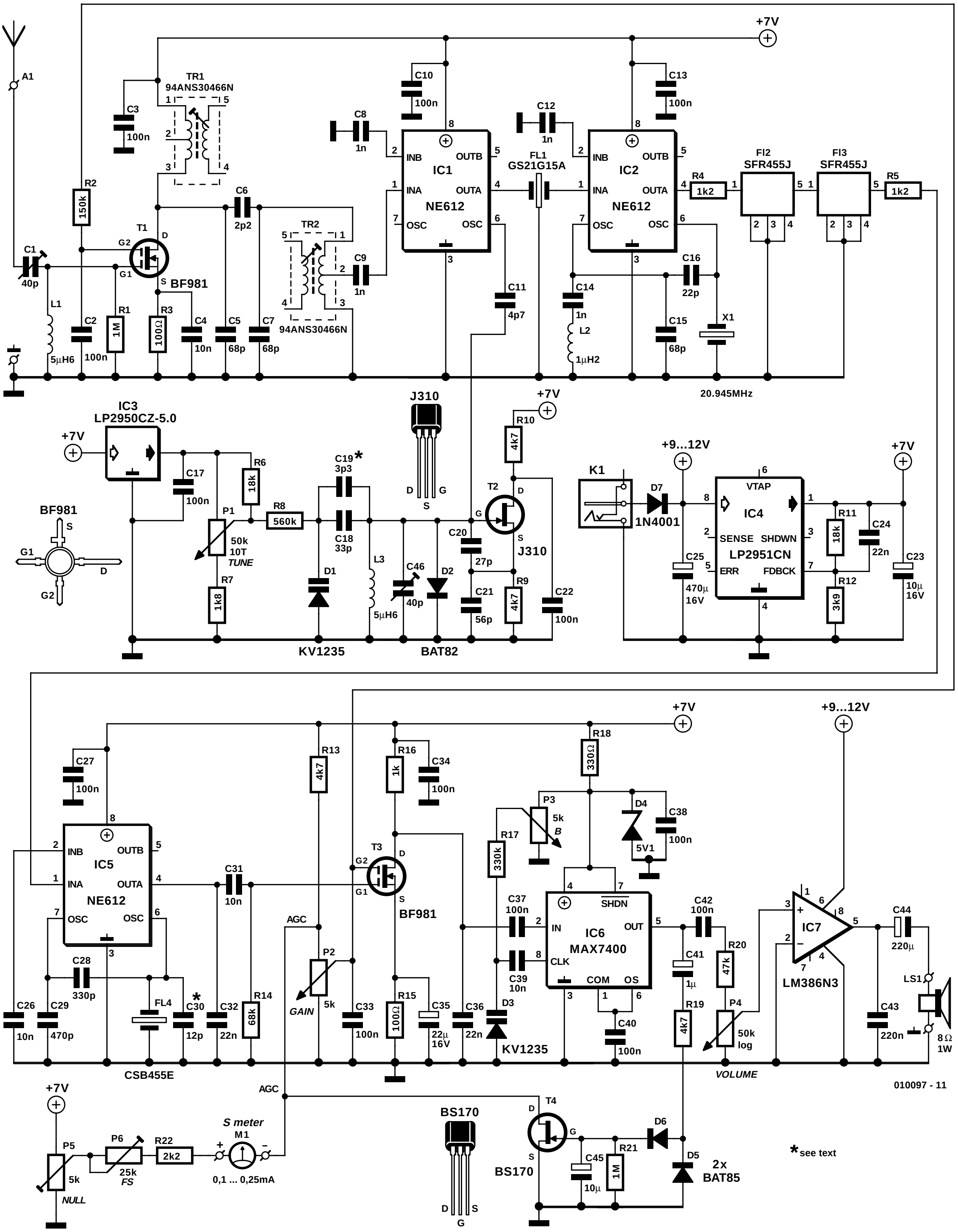


Figure 2. By using a mix of discrete components and integrated circuits, the author was able to keep the circuit relatively simple.

rejection is maximized.

In order to make this work, a LO3 frequency of 452.6 kHz has to be used (453 kHz – 400 Hz). This causes the image product to occur at a distance of at least 800 Hz from the filter passband where it is adequately suppressed. It could be argued that the present receiver is a triple-conversion superheterodyne but the designation 'double-conversion superhet with a direct-conversion demodulator' would seem equally legitimate.

Returning to the block diagram of the receiver, we have arrived at the audio section. This begins with an adjustable-gain amplifier whose main function is to suppress high-level interference. Next, there's a low-pass filter which determines the final selectivity of the receiver. The roll-off is adjustable between 500 Hz and 3200 Hz, which, after subtraction of the above mentioned lower limit of 400 Hz, results in a selectivity range of 100 Hz to 2.8 kHz. Here, a sharp eight-order filter is used which achieves more than 40 dB suppression at 1.25 times the roll-off frequency. As a matter of course, this filter is also a great when it comes to suppressing noise and other interference.

That almost completes our tour of the block diagram. What remains to be mentioned is the receiver's AF power amplifier and the AGC (automatic gain control). The first is a standard design throughout and the latter serves to reduce the gain of the two amplifier stages as a function of received signal strength, ensuring a reasonably steady audio level even if the received signal strength varies considerably.

VFO stability

For an SSB (single-sideband) receiver, a stable VFO is an absolute requirement. A number of practical tests indicated that the Colpitts oscillator used here requires about 3.5 minutes to warm up, and then exhibits a frequency drift of no more than 25 Hz within 5 minutes. Such stability is ample for SSB and CW reception, and obviates constant retuning.

The actual frequency stability of the VFO can not be measured until about 5 hours after the receiver has been built up, because the PCB requires quite some time to cool down and stabilize mechanically. VFO stability may be improved by purposely ageing the board. Package the PCB moist-free in a plastic (freezer) bag and leave it in the deep-freeze compartment of your refrigerator for a couple of hours. Take the bag out of the freezer and allow the PCB (still in the bag) to warm up to room temperature for an hour or so. Then put the bag on a (hot) central heating radiator. Allow it to cool down again to room temperature and then put the bag in the freezer again. Three such rounds will remove all mechanical stresses from the PCB and guarantee optimum VFO stability.

Circuit diagram — RF sections

Figure 2 shows the practical realisation of the block diagram.

Using high-pass filter C1-L1 d the input signal is cleaned of any unwanted components such as block-busting signals from nearby medium-wave transmitters. An additional function is antenna matching.

The RF input stage comprises a dual-gate MOSFET (T1) which couples high gain to a low noise figure. By making the voltage at gate 2 variable, the gain of T1 is adjustable across a range of about 20 dB. The gate is connected to the AGC circuit via resistor R2.

The critically coupled bandpass filter consisting of Tr1, Tr2, C5, C6 and C7 has a virtually flat response across a frequency range of about 500 kHz. The filter also suppresses image signals at 28.800 – 28.450 MHz by about 65 dB.

The first mixer is an NE612 (IC1) in a configuration that results in about 17 dB conversion gain.

The VFO is a Colpitts oscillator built around a FET type J310 (T2). The VFO is tuned by varicap D1. The supply voltage for the varicap tuning has an additional 5-V regulator of the low-drop type (IC3). Tuning is accomplished with a ten-turn pot, P1.

The first mixer is followed by a 21.4-MHz ceramic filter (FL1). Then follows another NE612 (IC2) which handles the frequency conversion to 455 kHz. The associated LO employs the oscillator components on board the NE612. Here, the oscillator is configured in overtone mode with quartz crystal X1 acting as the frequency-determining element.

The second mixer supplies the sum as well as the difference of the input frequency (21.4 MHz) and the LO frequency (20.94 MHz). Because we only want the difference frequency, the mixer is followed by a 455-kHz bandpas built from two ceramic filters type SFR455J (FL2 and FL3) connected in series ('cascaded'). The bandwidth of this combination amounts to about 3.4 kHz.

The third mixer is another NE612 (IC5) whose internal oscillator is tuned to about 452.6 kHz with the aid of ceramic resonator FL4.

Circuit diagram — AF section

Any RF residue at the output of IC5 is removed by C32. Next, the AF signal is amplified by T3. Here again, a BF981 is used because it allows adjustable gain to be implemented in a simple way. Control P2 allows the gain of T1 and T3 to be adjusted. Besides, the gain of the two MOSFETs in the receiver is automatically reduced (at large RF signal levels) by the AGC circuit built around T4, D5 and D6. The AGC voltage is derived from the audio signal at the output of IC6. In general, SSB reception will be optimum at minimum gain (turn down P2 as far as possible). This way you will reduce the interference (and possible blocking) caused by nearby transmitters and atmospheric noise.

Next, we will discuss one of the most important elements of the receiver: the variable low-pass filter. Here, a MAX7400 (IC6) is used. The MAX7400 is an integrated 8th-order elliptical filter IC using switched capacitors. The roll-off frequency (hence the receiver selectivity) is adjusted by varying the voltage at pin 8. That is accomplished using varicap diode D3 and a direct voltage taken from from the wiper of P3. In this way, P3 enables the optimum receiver bandwidth to be set between 100 Hz and about 2.8 kHz to match any mode and modulation form you want to listen to (or decode on your PC).

Two more circuit parts are left to discuss: the S meter and the AF power amplifier.

The S (signal strength) meter (M1) is controlled by the AGC voltage at the drain of T4. The moving-coil instrument will only start to deflect at signals of a couple of μV, so it will not respond to extremely weak signals. Full-scale deflection (FSD) is reached at an RF signal level of about 200 µV. Meter zero and meter FSD may be adjusted on P5 and P6 respectively.

The AF amplifier is built around the familiar LM386N3 integrated circuit which supplies up to 0.7 watts of audio power. Because the LM386 boasts a supply ripple rejection of 50 dB, it may be powered from the receiver's unregulated supply voltage. If desired, headphones may be used instead of a small loudspeaker. Provided P4 is turned up a bit, the AF signal level will be sufficient to drive a PC's serial port line, directly or via an interface, for the decoding of facsimile, SSTV or CW signals on a computer running JVFAX or Hamcomm.

Power Supply

Depending on the audio volume set on P4, the receiver will consume 30 to 150 mA at a supply voltage of 9 volts. Because the circuit has an on-board voltage regulator (IC4), a low-cost mains adaptor (a.k.a. battery eliminator) with an output voltage of 9 to 12 VDC is perfect for the job — and safe, too! Even the smallest of these adaptors are usually capable of supplying 300 mA and more. Of course, you are welcome to build your own dedicated power supply for the receiver — simply use a 9-volt PCB mount transformer, a bridge rectifier and a reservoir capacitor of 470 µF/25 V. Do observe the relevant electrical safety precautions when building such a supply!

Construction

Elektor labs have once again succeeded in designing a beautiful PCB, see the copper track layout and component mounting plan in **Figure 3**. As you can see, the entire receiver, including all controls and the supply connection, is accommodated on the board. What's more, despite it being

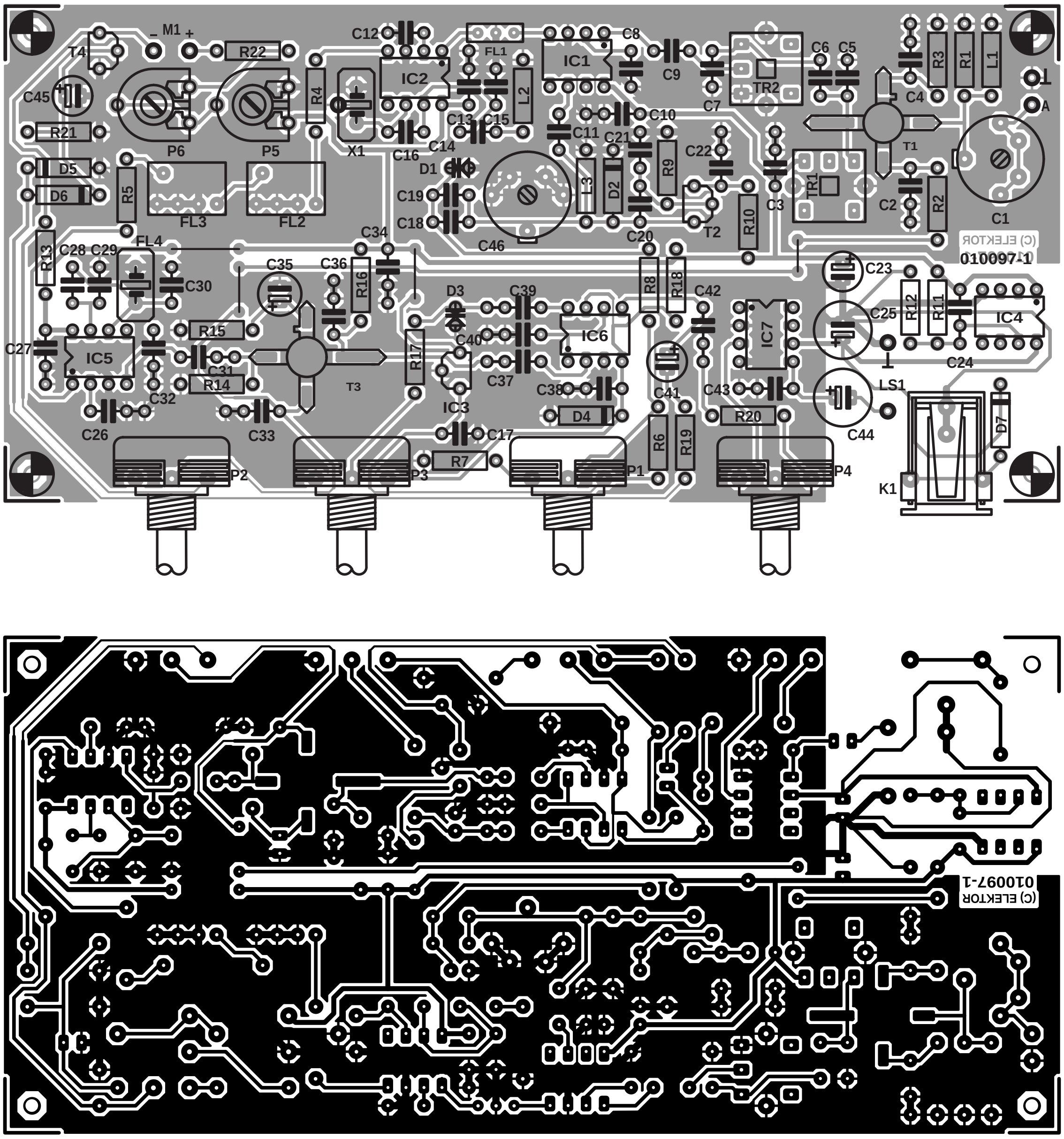


Figure 3. Copper track layout and component mounting plan for the PCB designed for the 2-m receiver (board available ready-made through Readers Services).

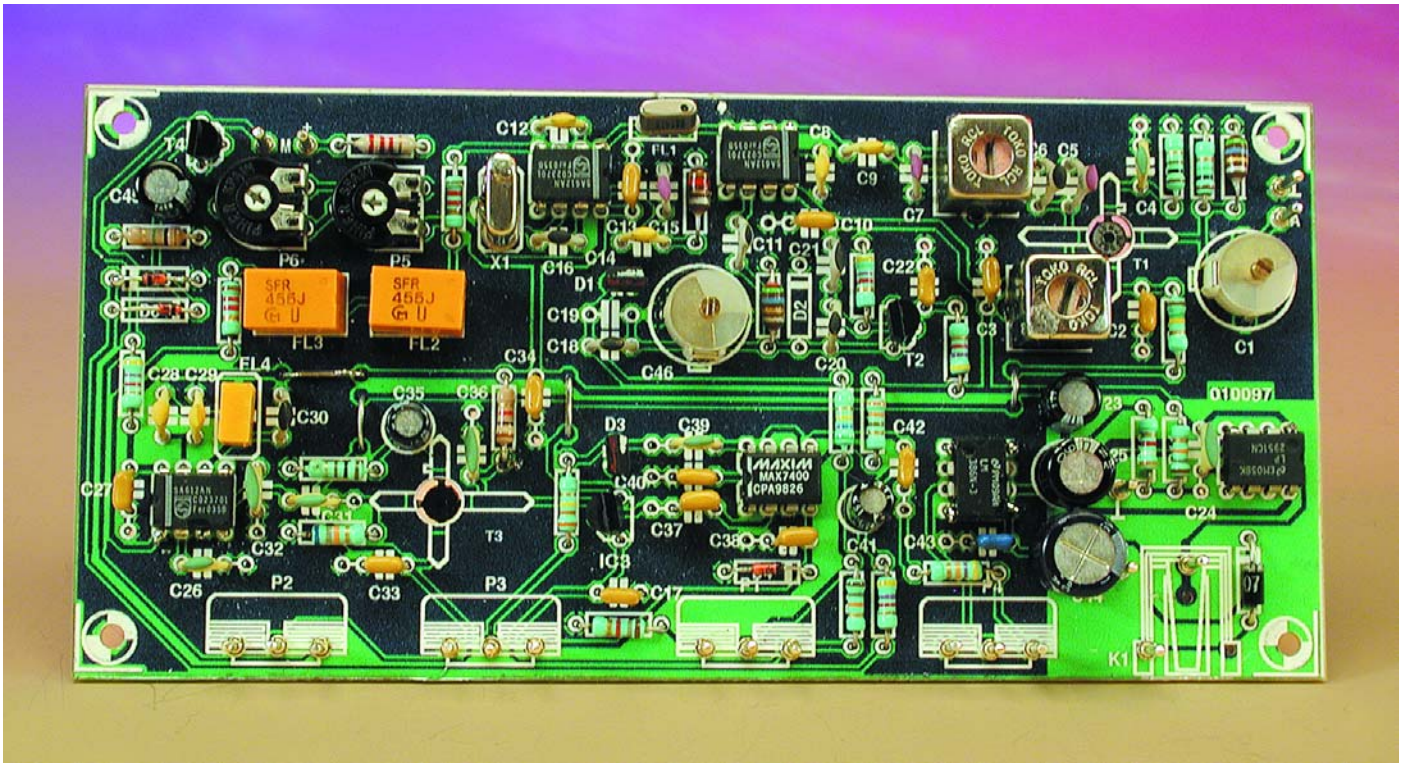


Figure 4. Prototype of the receiver built and tested in the Elektor labs. Note that MOSFETsT1 and T3 are mounted at the underside of the board!

single sided, the PCB has a minimum number of wire links — just four!

The connection points for the antenna, loudspeaker and moving-coil meter M1 are clearly labelled on the board, so little can go wrong in that department. Of course, the four potentiometers may also be mounted off the board and

COMPONENTS LIST

Resistors:

R1,R21 = 1MΩ
R2 = 150kΩ
R3,R15 = 100Ω
R4,R5 = 1kΩ2
R6,R11 = 18kΩ
R7 = 1kΩ8
R8 = 560kΩ
R9,R10,R13,R19 = 4kΩ7
R12 = 3kΩ9
R14 = 68kΩ
R16 = 1kΩ
R17 = 330kΩ
R18 = 330Ω
R20 = 47kΩ
R22 = 2kΩ2
P1 = 50kΩ 10-turn cermet
P2,P3 = 5kΩ linear
P4 = 50kΩ
P5 = 5kΩ preset
P6 = 25kΩ preset

Capacitors:

C1,C46 = 40pF trimmer
C2,C3,C10,C13,C17,C22,C27,C33,C34, C37,C38,C40,C42 = 100nF
C4,C26,C31,C39 = 10nF
C5,C7,C15 = 68pF
C6 = 2pF2
C8,C9,C12,C14 = 1nF
C11 = 4pF7
C16 = 22pF
C18 = 33pF
C19 = 3pF3 *
C20 = 27pF
C21 = 56pF
C23 = 10μF 16V radial
C24,C32,C36 = 22nF
C25 = 470μF 16V radial
C28 = 330pF
C29 = 470pF
C30 = 12pF
C35 = 22μF 16V radial
C41 = 1μF 16V radial
C43 = 220nF
C44 = 220μF 16V radial
C45 = 10μF 16 V radial

Semiconductors:

D1,D3 = KV1235 (1 V/500 pF, 8 V/25 pF)
D2 = not used (do not mount)
D4 = zener diode 5V1, 400mW
D5,D6 = BAT85
D7 = 1N4001
IC1,IC2,IC5 = NE612 or SA612AN
IC3 = LP2950CZ-5.0 (possibly 78L05)
IC4 = LP2951CN
IC6 = MAX7400
IC7 = LM386N3
T1,T3 = BF981
T2 = J310
T4 = BS170

Miscellaneous:

FL1 = GS21G15A or GS21G15B
FL4 = CSB455E
Fl2,Fl3 = SFR455J
L1,L3 = 5μH6 miniature choke
L2 = 1μH2 miniature choke
LS1 = 8 W/1W loudspeaker
M1 = 0.1 – 0.25 mA moving-coil meter
Tr1,Tr2 = 94AES30466N or 94ANS30466N
X1 = 20.945MHz quartz crystal (parallel resonance, 3rd overtone, 2x20pF)
K1 = mains adaptor socket, PCB mount
PCB, order code **010097-1** (see Readers Services page)

connected to it by short wires. In that case, volume pot P4 requires screened cable.

Although RF circuits are reputedly a tad difficult to build, that does not apply to this receiver. Anyone with some experience in building electronic circuits will not have the slightest trouble with this particular board. As a notable detail, the metal case of quartz crystal X1 has to be connected to ground by a short wire.

Unusually (at least to the uninitiated), MOSFETs T1 and T3 have to be mounted at the solder side of the board.

Although a component labelled D2 is included in the circuit diagram, it is not actually used. In our prototype of the receiver, the VFO stability was better without D2.

If you stick to the parts list and the component overlay, take your time and solder carefully, there is little that stands in the way of success.

A good way to check if your construction skills are any good is to compare your receiver board with the prototype shown **Figure 4**.

You are free to choose any suitable enclosure for the receiver. Although a metal case is preferred for this kind of circuit, we found that our prototype gave good performance and little sign of interference or unwanted radiation when fitted in an ABS case.

Adjustment

Do not yet connect an antenna. Turn up the volume pot a little. Turn tuning pot P1 7.5 turns starting from the lowest setting. Also starting from the minimum setting, adjust VFO trimmer C46 until a whistle is heard.

Connect a not too long antenna to the receiver input and adjust input trimmer C1 to maximum capacitance (full mesh). Turn the cores in Tr1 and Tr2 fully down, and then back up one turn. Next, alternately adjust the cores for highest noise output. Finally, peak C1 for maximum noise output.

The S-meter circuit has to be adjusted without an antenna connected to the receiver. Turn P6 to mid-travel and then adjust P5 for zero deflection on the meter. Use a short piece of wire to temporarily take the drain of T4 to ground, then adjust P6 for minimum meter deflection. Remove the short circuit. If the meter does not return to zero, repeat the above steps a few times.

Two more details need to be discussed which we feel are relevant, although strictly speaking they do not really belong to the adjustment procedure.

The circuit diagram shows that board space has been reserved for an additional capacitor C19 in parallel with C18. In most cases, C19 will not be required. However, those of you in possession of, or with access to, an accurate frequency meter or an RF signal generator may care to ‘tweak’ the receiver’s tuning range by adding a padding capacitor of which the value is determined by trial an error.

Similar considerations apply to padding capacitor C30 in parallel with FL4. This capacitor may be used to cope with the tolerance on the oscillation frequency of the ceramic resonator. Only if the receiver seems to sound a bit dull (lack of treble), C30 may be given a slightly lower value.

Practical use

After switching on the receiver, allow the VFO to warm up for a couple of minutes. Initially, set the bandwidth and gain controls (P3 and P2 respectively) to maximum.

When tuning to a station using P1, you’ll find that you need to set the ‘pitch’ first. It is convenient at that point to reduce the gain somewhat to a level at which the signal sounds clear. Next, carefully turn the tuning control again for best reception.

The next step is to reduce the bandwidth until the received signal just remains undistorted. In this way, noise and interference (QRM) may be considerably reduced. When listening to a CW station, the bandwidth may be vastly reduced. If, for instance, the dots and spaces are reproduced at 700 Hz or so, the receiver bandwidth may be reduced to as little as 300 Hz. Having marked the best setting of P3 for various modes you will be able to get optimum results in no time at all when tuning across the 20-m band.

Antenna

At times, signals in the 20-m amateur radio band may be so strong that a 10-cm wire is enough for reasonable reception. However, for ‘normal’ listening you’ll find that the receiver performs admirably with a wire of about two metres length connected to the antenna input. Even without special propagation conditions, this (indoor) wire should pick up stations within a range of 3,000 kilometres or so. Under favourable weather conditions, the 20-m band will burst open and swarm with activity, and you’ll be surprised how much can be picked up with a truly modest antenna.

Best results are obtained when using a long wire antenna with a length of about 10 metres, hung up outside, well removed from sources of electrical interference. On the down side, such an antenna may easily overload the receiver to the extent that QRM becomes so high the AGC starts to work when no signal is heard! In such cases, a variable attenuator may have to be inserted in the antenna line.

Finally, note that C1 requires re-adjustment after any change to the antenna or the length of it.

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